DISPLAY AND SENSOR APPARATUS

This Nonprovisional application claims priority under 35 U.S.C. §119(a) on Patent Application No. 0304587.9 filed in Great Britain on February 28, 2003, the entire contents of which are hereby incorporated by reference.

Technical Field

The present invention relates to an active matrix display and sensor apparatus.

Background to the Invention

Active matrix liquid crystal displays (AMLCDs) may be used in products which require an input function. For example, mobile telephones and personal digital assistants (PDAs) may display information to a user on an AMLCD and require input from the user, for example from a telephone keypad. Alternatively or additionally, AMLCDs may be required to adjust automatically to environmental conditions, such as ambient light or temperature. In such cases, a sensor is required to accept an input from outside the apparatus. In known arrangements, such sensor functionality has been provided by adding extra components to the display. For example, in order to provide a touch input to form a "touch screen", extra layers have to be added to the front of the display. Providing such functionality therefore adds to the complexity and cost of such apparatuses.

T Tanaka et al, "Entry of Data and Command for an LCD by Direct Touch: An Integrated LCD Panel", SID 1986 discloses an arrangement which provides a touch sensor function in a passive matrix display. In this arrangement, any capacitance change of a liquid crystal layer caused by a touch input is detected using the passive matrix scan and data lines. However, performance is limited and complexity and cost are increased by having to provide suitable display driver and sensor circuits off the panel forming the display.

US 6 028 581 discloses an active matrix liquid crystal display having an integrated sensor arrangement. In this arrangement, photodiodes are integrated at each pixel (picture element) and are arranged to detect touch input, for example by a stylus, or to detect an image formed on the display. However, such an arrangement requires changes

to the active matrix which substantially reduce the fill-factor and hence the image quality of the display.

JP 5-250093 discloses an active matrix liquid crystal display having an arrangement for detecting the coordinates of an input pen when in contact with the display. The input pen generates a fixed voltage, altering the data on the signal electrode lines with which it is contact. The differences between the altered signal and the input data are used to determine the point of contact. The signals induced by the input pen are registered in the addressing matrix and this does not require the presence of a liquid crystal layer.

Summary of the Invention

According to the invention, there is provided an active matrix display and sensor apparatus, comprising: an array of display picture elements arranged as rows and columns, each picture element having a display data input for receiving image data to be displayed and a scan input for enabling input of image data from the data input, the data inputs of the picture elements of each column being connected to a respective column data line and the scan inputs of the picture elements of each row being connected to a respective row scan line; a data signal generator for supplying data signals to the column data lines; a scan signal generator for supplying scan signals to the row scan lines; and an output arrangement connected to the column data lines for outputting sensor signals generated by and within the display picture elements in response to external stimuli.

The sensor signals may be generated by and within the optically variable region of the display picture elements.

The apparatus may comprise a display substrate on which are integrated the data signal generator, the scan signal generator, the output arrangement, and electronic components of the array. The data signal generator may be disposed along a first edge of the array and the output arrangement may be disposed along a second edge of the array opposite the first edge.

Each picture element may comprise an image generating element and an electronic switch. Each image generating element may comprise a liquid crystal element. Each picture element may comprise a storage capacitor. Each electronic switch may comprise a thin film transistor. Each transistor may have a gate connected to the picture element scan input, a source connected to the picture element data input, and a drain connected to the image generating element.

The apparatus may comprise a controller for controlling at least one of the data and scan signal generators and the output arrangement. The controller may be integrated on the display substrate. The apparatus may comprise active devices embodied as thin film transistors.

The controller may be arranged to control which of the picture element sensor signals are output by the output arrangement. The controller may be programmable to determine which of the picture element sensor signals are output by the output arrangement. The controller may be reprogrammable during operation of the apparatus to change which of the picture element sensor signals are output by the arrangement. The controller may be arranged to control operation of the data and scan signal generators and the output arrangement to define alternate image writing phases and sensor reading phases. A frame of image data may be written to the array during each writing phase. Each reading phase may occur during a vertical blanking period between consecutive writing phases.

At least one row of image data may be written to the array during each writing phase. Each reading phase may comprise outputting the sensor signals from at least one row of picture elements after the at least one row to which image data were written during the preceding writing phase.

Sensor signals of all of the picture elements may be output during each reading phase.

The sensor signals of a proper subset of all of the picture elements may be output during each reading phase. The sensor signals of the same proper subset of picture elements may be output during the reading phases. As an alternative, the proper subset of picture

elements may comprise different picture elements during each reading phase of a group of reading phases such that the sensor signals of all of the picture elements are output during each group of reading phases.

The proper subset of picture elements may comprise at least one group of rows of picture elements, the or each group containing at least one row. The at least one group may comprise a plurality of groups which are substantially evenly spaced in the column direction of the array. The at least one group may comprise a plurality of adjacent rows.

The controller may be arranged to control operation of the data and scan signal generators and the output arrangement to write image data to and to read sensor signals from the array simultaneously. The data signal generator may be arranged to supply image data to first ones of the data lines and the output arrangement may be arranged to read sensor signals simultaneously from second ones of the data lines different from the first ones of each row of the picture elements. The first and second ones may be the same for all of the rows of the picture elements.

The output arrangement may be responsive to a characteristic of the picture elements comprising at least one of voltage, current, stored charge and capacitance.

The output arrangement may comprise a plurality of sense amplifiers connected to the column data lines. The number of sense amplifiers may be less than the number of data lines and each sense amplifier may be connectable to any one of a respective set of the data lines by a respective first multiplexer. The output arrangement may comprise a plurality of analog/digital converters connected to outputs of the sense amplifiers. The number of converters may be less than the number of sense amplifiers and each sense amplifier may be connectable to any one of a respective set of the sense amplifier outputs by a respective second multiplexer. The output arrangement may comprise a shift register for converting parallel outputs from the converters to a serial output.

It is thus possible to provide an apparatus in which sensor functionality is integrated with an active matrix display, such as an active matrix liquid crystal display. By using the active matrix as a means of input, no modification of the active matrix or driver

circuitry is required in order to provide the sensing functionality. There is no need for reduced pixel aperture or reduced fill-factor so that display quality need not be impaired by integration of the sensing functionality. The active matrix and driver arrangements may be of standard design and the additional sensing functionality may be provided by, for example, integrating additional circuitry along a side of the active matrix which would not otherwise have been used.

In those embodiments having a controller which is programmable, it is possible to provide an apparatus in which sensor and/or display operation may be controlled by software, for example in accordance with the requirements of a particular application. Thus, the same apparatus may be used in a variety of operational modes according to application and the software or programming to define the actual mode of operation may easily be provided from an external source, such as processing hardware and software for supplying the image data to the apparatus. It is also possible for such programming to be associated with displayed images and for this to be changed during operation. For example, if a control icon is sent for display, the apparatus may at the same time be arranged to respond to touch in the region of the icon so as to provide a touch display function without requiring any additional hardware or additional layers to be provided.

Brief Description of the Drawings

Figure 1 is a block schematic diagram of an active matrix display and sensor arrangement constituting an embodiment of the invention;

Figure 2 is a timing diagram illustrating a first mode of operation of the apparatus of Figure 1;

Figure 3 is a timing diagram illustrating a second mode of operation of the apparatus of Figure 1;

Figures 4 to 6 are diagrams similar to Figure 1 illustrating further modes of operation of the apparatus of Figure 1;

Figure 7 is a circuit diagram illustrating a sense amplifier and converter of the apparatus of Figure 1;

Figure 8 is a block schematic diagram illustrating a first example of the output arrangement of the apparatus of Figure 1; and

Figure 9 is a block schematic diagram illustrating a second example of the output arrangement of the apparatus of Figure 1.

Like reference numerals refer to like parts throughout the drawings.

Detailed Description of Embodiments of the Invention

The active matrix liquid crystal display and sensor apparatus is formed on a display substrate illustrated diagrammatically at 1 and comprises a timing and control circuit 2 connected to an input 3 for receiving timing and control signals together with image data to be displayed. The circuit 2 supplies the appropriate signals to a data signal generator in the form of a display source driver 4 and a scan signal generator in the form of a gate driver 5. The drivers 4 and 5 may be of any suitable type, such as of a standard or conventional type, and will not be described further.

The display source driver 4 has a plurality of outputs which are connected to but isolatable from a plurality of matrix column electrodes which act as column data lines for the active matrix of picture elements (pixels) indicated at 6. The display source driver outputs may, for example, only be connected to the data lines when the driver is enabled by the control circuit 2. The column electrodes extend throughout the height of the active matrix 6 and each is connected to data inputs of a respective column of pixels. Similarly, the driver 5 has a plurality of outputs connected to row electrodes which extend throughout the width of the matrix 6. Each row electrode acts as a row scan line and is connected to scan inputs of the pixels of the respective row.

One of the pixels is illustrated in more detail at 10 and is of a standard active matrix liquid crystal type. The pixel 10 comprises an electronic switch 11 in the form of a poly-silicon thin film transistor whose source is connected to the column electrode 12, whose gate is connected to the row electrode 13, and whose drain is connected to a liquid crystal pixel image generating element 14 and a parallel storage capacitor 15.

Figure 1 illustrates diagrammatically the physical layout of the various parts of the arrangement. All of the electronics are integrated on the display substrate 1 with the display source driver 4 being disposed along the upper edge of the matrix 6 and the gate driver 5 being disposed along the left edge of the matrix 6. The drivers 4 and 5 and the matrix 6 and their relative dispositions may be standard or conventional.

The arrangement further comprises an output arrangement 19 which is disposed along the bottom edge of the matrix 6. The arrangement 20 comprises a plurality of sense amplifiers 20 which are controlled, for example enabled, by a control signal from the circuit 2 and whose inputs are connected to respective column electrodes. The outputs of the sense amplifiers are supplied to an analogue-to-digital conversion block 21, which converts the analogue values sensed by the sense amplifiers 20 to parallel digital outputs. The outputs of the conversion block 21 are connected to read-out shift registers 22, which convert the parallel output data to serial output data and supply this to a sense output 23 of the arrangement.

The references to rows and columns are not intended to be limited to horizontal rows and vertical columns but, instead, refer to the standard well-known way in which image data are entered row by row. Although pixel rows are normally arranged horizontally and pixel columns vertically in displays, this is not essential and the rows could, for example, equally well be arranged vertically with the columns then being arranged horizontally.

In use, image data for display are supplied by any suitable source to the input 3 of the arrangement and are displayed by the active matrix 6 in accordance with the operation of the drivers 4 and 5. For example, in a typical arrangement where the display is

refreshed row-by-row, pixel image data are supplied serially as image frames with a frame synchronisation pulse VSYNC indicating the start of each frame refresh cycle as shown in Figure 2. Rows of pixel image data are entered one after the other in the display source driver 4 and a scan signal is supplied to the appropriate row electrode for enabling the image data to be stored in the appropriate row of pixels. Thus, the pixel rows of the matrix 6 are refreshed a row at a time with the gate driver 5 usually supplying scan signals a row at a time starting at the top row and finishing at the bottom row when a frame refresh cycle has been completed.

In the mode of operation illustrated in Figure 2, each display frame occupies a time t_d and includes a refresh part during which the display data are used to refresh the matrix 6 of pixels a row at a time followed by a vertical blanking period VBL. At the end of the display frame period, a sensor frame synchronisation pulse is supplied to initiate a sensor frame of period t_s forming a sense phase of the apparatus.

During the sense phase, outputs of the display source driver 4 are isolated from the column electrodes and the sense amplifiers 20 are enabled by the circuit 2. The gate driver 5 again scans the row electrodes one at a time in turn from the top of the matrix 6 to the bottom and the signals sensed by the sense amplifiers 20 are converted to digital form by the conversion block 21 and read out a row at a time by the shift registers 22. The shift registers 22 may produce a pure "single bit" serial output or may produce multi-bit serial word outputs.

During the display phase, when the pixel 10 is being refreshed, the gate driver 5 supplies a scan signal to the row electrode 13, which thus turns on the thin film transistor 11. The display source driver 4 supplies a voltage representing the desired visual state of the image generating element simultaneously to the column electrode 12 and charge for determining the desired image appearance is transferred from the column electrode 12 to the storage capacitor 15 and to the image generating liquid crystal element 14, which also acts as a capacitor. The voltage across the element 14 causes this to display the desired image grey level in the known way. The liquid crystal pixel image generating element 14 comprises the optically variable region which gives rise to the display action.

Standard display pixels such as that illustrated at 10 may be used to sense external stimuli without requiring any substantial modification. For example, each display pixel may be used to detect a touch input, as described in T. Tanaka et al, "Entry of Data and Command for an LCD Direct Touch: An Integrated LCD Panel", SID 1986. Pressure applied to the top glass plate of an LCD assembly causes deformation in the liquid crystal around the area to which pressure is applied. This deformation causes a detectable change in capacitance of the liquid crystal element 14. This change in capacitance represents a signal generated by and within the optically variable region of the liquid crystal element 14.

During the sense phase when the row containing the pixel 10 is enabled by the scan signal from the driver 5 on the row electrode 13, the element 14 together with the capacitor 15 are connected to the column electrode 12 by the transistor 11. Any variation of characteristic in the pixel as a result of an external stimulus is thus made accessible to the one of the sense amplifiers 20 connected to the column electrode 12 so that the characteristic resulting from the stimulus is converted to an analogue value by the sense amplifier. The characteristic sensed by the sense amplifiers may be pixel voltage, current, stored charge or capacitance or may be a combination of any of these.

The cycle of operation is then repeated starting with the VSYNC pulse which initiates refreshing of the display with the next frame of display data. The display frame time t_d may or may not be equal to the sensor frame time t_s.

Although Figure 2 illustrates the sensor frame occurring after the vertical blanking period VBL of the preceding display frame, the sensor frame may alternatively occur within the blanking period of the display frame. All of the rows may be scanned for sensor data during the sensor frame. Alternatively, a different proper subset of the rows of pixels may be scanned during each of a plurality of frames such that the entire matrix is scanned for sensor data over the period of the plurality of display frames. For example, the number of rows scanned for sensor data may be dependent on the display frame rate and the patterns of scanned rows may be determined by software in the

timing and control circuit 2. Such an arrangement may be used to provide an improvement in the quality of the displayed image, as compared with scanning the whole matrix during the sensor frame, and may allow the display to maintain as high a frame rate as for conventional displays which do not provide sensing functionality. The term "proper subset" as used herein is defined as being a subset of the full set, excluding the cases of the empty set and the full set.

Figure 3 illustrates an alternative mode of operation, in which display and sensing phases are performed during each row refresh period or row time. The start of each row time is defined by a horizontal synchronisation pulse HSYNC. The first or top row of pixels of the matrix 6 is enabled by the first scan pulse of the frame from the gate driver 5 so that the transistors 11 of the pixels 10 of the first row are switched on and the liquid crystal elements 14 of that row are connected, together with the storage capacitors 15, to the respective column electrodes 12. The circuit 2 enables the sense amplifiers 20 while ensuring that the display source driver outputs are disconnected or electrically isolated from the electrodes 12 so as not to interfere with the sensing operation. In embodiments where the display source driver 4 is such that its outputs are isolated from the electrodes 12 when it is inactive, no modification is necessary and the driver 4 may be of standard or known type. Alternatively, if the driver outputs are not isolated by the design of the driver circuit, means for isolating the outputs from the electrodes 12 are provided and are controlled by the circuit 2.

In Figure 3, the sensor data for the first row are indicated at S1. At the end of the sense phase, the output arrangement 19 is prevented by the circuit 2 from responding to the pixel characteristics of the enabled first row of the matrix 6. Display data in the form of the appropriate analogue voltages for the desired pixel optical characteristics are supplied by the display source driver 4 to the column electrodes 12 and the appropriate charge for each pixel is transferred to the element 14. The scan signal for the first row is then disabled by the gate driver 5 so that the transistors 11 of the pixels 10 are switched off to isolate the elements 14 from the column electrodes 12. This completes refreshing of the first row of the matrix 6.

This cycle of operations is then repeated for each row of the matrix 6 until the whole matrix has been scanned for sensor signals and refreshed with a frame of image data. Because the sensing phase would corrupt or destroy display data stored at each pixel, the sensing phase is performed before the display refreshing phase for each row of the matrix 6.

Figure 4 illustrates another mode of operation in which the whole of the matrix 6 is refreshed by each frame of image data but only every Nth row of pixels is used during the sense phase, where N is an integer greater than 1 and has the value 3 in the embodiment illustrated in Figure 4. This mode of operation may be performed using either of the modes illustrated in Figures 2 and 3. By selecting the value of N, the spatial resolution of the sensing function can be selected in accordance with requirements. For many applications, the required sensing resolution is substantially less than the required display resolution. Reducing the number of rows which are scanned during the sense phase reduces the power consumption and the time taken for the matrix 6 to be scanned during the sense phase.

The actual pattern of rows which are scanned during the sense phase may be determined by software in the timing and control circuit 2. For example, the value of N may be set by the source of signals supplied to the input 3 of the apparatus. Alternatively, in applications where uniform resolution of sensing is not required, the pattern of rows for the sense phase may be entered in the circuit 2 and the rows which are sensed may not be evenly spaced across the matrix 6.

Figure 5 illustrates another mode of operation in which only some of the pixel rows are scanned for sensor signals. A group of, in this case four, consecutive or adjacent rows of pixels are scanned for sensing during each sensor frame. Again, the number of rows which are scanned may be determined by software in the circuit 2. Further, this mode may be combined with the mode illustrated in Figure 4 such that spaced groups of consecutive rows are scanned for sensing.

In Figures 4 and 5, those rows which are scanned during sensor operation are illustrated by bold lines such as 13a.

Figure 6 illustrates a further mode of operation in which only some of the columns of pixels are scanned during sensor operations. Again, those columns which are scanned are illustrated by bold lines such as 12a. In this mode, display and sensing operations are carried out simultaneously but with each column of pixels performing sensing or display but not both. Those columns of pixels being used for display are connected by the column electrodes to the display source drivers 4 whereas those columns of pixels being used for sensing are isolated from the outputs of the drivers 4 and are connected to the sense amplifiers 20. In particular, each column of pixels should not be connected simultaneously to a display driver output and a sense amplifier because the display function interferes with the sensing function and vice versa.

Again, the pattern of columns for sensing may be determined by software programmed in the circuit 2. The pattern of source lines connected to the drivers 4 or the sense amplifiers 20 may change from row to row and/or from frame to frame. Programming of the circuit to control these patterns may be changed from time to time by reprogramming so as to change the patterns and this may even be done from row to row or from frame to frame so as to achieve the desired patterns of sensing and display pixels.

The modes of operation described hereandbefore are not necessarily mutually exclusive and may be combined. Thus, any desired display or sensing pattern may be achieved without having to scan pixels unnecessarily.

These techniques may be used so as to relate the area of the matrix 6 to be scanned for sensor data to the displayed image. For example, an icon may be displayed and only the area where the icon is displayed may be scanned for sensor data.

The sense amplifiers 20 and the analogue-to-digital conversion 21 may be embodied by any suitable arrangements and examples of these are illustrated in Figure 7. In this example, each sense amplifier is embodied by a charge transfer amplifier 20a as disclosed in H.Morimura et al, "A Novel Sensor Cell Architecture and Sensing Circuits Scheme for Capacitive Fingerprint Sensors", IEEE Journal of Solid-State Circuits, vol.

35, no. 5, May 2000. Each converter may be embodied as a charge re-distribution analogue-to-digital converter as shown at 21a and as disclosed in D.Johns and K.Martin, "Analogue Integrated Circuit Design", Wiley, 1997. The contents of both documents are incorporated herein by reference and these arrangements will not therefore be described further.

Figure 8 illustrates an arrangement in which the number of analogue-to-digital converters 21a is less than the number of charge transfer amplifiers 20a. In this case, each converter 21a is connected via a multiplexer 30 to the outputs of several charge transfer amplifiers 20a. The multiplexer 30 is controlled so as to connect one amplifier 20a at a time to the input of the converter 21a. Figure 9 shows a modification to this arrangement in which the number of charge transfer amplifiers 20a is less than the number of column electrodes 12. Each charge transfer amplifier 20a is connected by a further multiplexer 31 to its set of column electrodes 12 with the multiplexers 31 being arranged to connect the column electrodes one at a time to the input of the corresponding amplifier 20a. Such arrangements reduce the substrate area required for the output arrangement and may be used to avoid having to reduce display resolution or increase the display size.

The output arrangement 19 may be formed on the substrate 1 using any of the techniques which are known for forming the drivers 4 and 5 and the active matrix 6 on the display substrate. For example, the active devices of the whole apparatus may be formed as poly-silicon thin film transistors. It is therefore possible to add the output arrangement 19 without requiring any or any substantial number of additional steps during the manufacturing process.

It is thus possible to provide an apparatus which adds integrated sensor functionality to a standard substantially unmodified type of active matrix liquid crystal display. The drivers 4 and 5 and the active matrix 6 may be of standard or known type and do not require any, or any substantial, modification in order to provide the sensor functionality. Thus, the appearance of the display need not be affected by the sensor functionality, which is effectively provided by the addition of the output arrangement 19 on a part of the substrate 1 which would not otherwise have been used. By controlling the timing

and sequence of the scan pulses, the arrangement may be operated in different ways, for example to provide different modes of display and sense phases. Also, the resolution and frequency of sensing can be set by control signals supplied to the circuit 2.